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A DIFFERENTIAL VOLUMENOMETER.

BY *Keisley*
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A DIFFERENTIAL VOLUMENOMETER.

BY ALBERT P. CARMAN.

16 Apr 09
H.L.
THE volumenometer or stereometer, invented by the French military engineer Say in 1797,¹ remains in some of its forms, the only instrument for determining the volumes of small irregular bodies and powders which cannot be immersed in a liquid. The fundamental principle of all volumenometers is the determination from Boyle's law of the volume of air imprisoned in a space V by observing the change of pressure corresponding to a given change of volume. The volume is changed in all forms by raising and lowering mercury in a graduated tube, the upper part of which is the vessel V . Then placing the body of volume x in the same space V , the new volume of air is found, and thus by subtraction, the volume x of the body is gotten. Most of the five or six volumenometers² which have been described and used in scientific work, differ simply in the methods of raising and lowering the mercury, that is, in the means of changing the volumes and measuring the change. In the volumenometer of Oberdeck we have an instrument which is distinct from previous forms in being differential. It was from a study of Oberdeck's instrument that the present work started. The first form described below was started simply as an improved form of Oberdeck's instrument, but it was found to have some new features both in theory and manipulation, and this led to experiments with modifications, as will be described.

Kirley J.
Oberdeck's form is shown in Fig. 1; V and V' are two equal glass cups which can be closed by ground-glass plates; T and T' are graduated glass tubes fixed on a horizontal board and joined in a U at B . The U is connected by rubber tubing with a mercury

¹ Say, Ann. de Chem. et Phys. (1), XXIII., 1797.

² Regnault, Ann. de Chem. et Phys. (3), XIV., 1845. Kopp, Liebig's Ann., XXXV., 1840. Ruedorf, Wied. Ann., VI., 1879. Paalzow, Wied. Ann., XIII., 1881. Oberdeck, Wied. Ann., LXVII., 1899. Zehnder, Ann. d. Phys., X., 1903; XV., 1904.

reservoir R . By raising and lowering R , the volume of air imprisoned in V and V' can be changed. An essential feature of Oberdeck's instrument is that the pressures on the two sides are

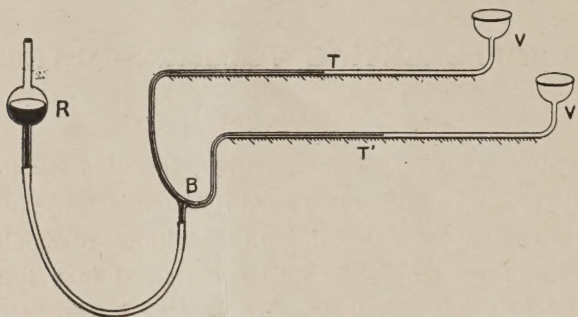


Fig. 1.

always equal, since the two tubes are on the same level. The increments of volume are read by the position of the mercury columns in the graduated tubes T . Some experiments showed that there

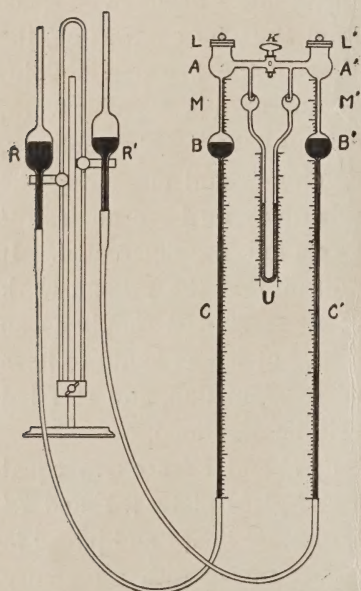


Fig. 2.

must be considerable error in such readings owing to the lag of the mercury in horizontal tubes. It is also evident that the tubes T must be made long to get great sensitiveness, since the device of enlargements is not possible in horizontal tubes. To improve these features the instrument shown in Fig. 2 was made. A and B are vessels, each of about 5 c.c. capacity. A lid L can be clamped air-tight on A . M is a glass tube connecting A and B . C is a graduated glass tube. This tube is connected by rubber tubing with a mercury reservoir R . This reservoir can be raised and lowered so as to change the volume of the air imprisoned in $AMBC$. On the

right side we have $A'M'B'C'R'$, a duplicate of the parts on the left side. The cups are connected by a sensitive manometer, containing

a light aniline liquid. A stopcock K allows the ready equalizing of the pressures on the two sides. The whole is mounted on a vertical board; on the same base is a vertical rod to which the platform carrying the mercury reservoirs is clamped. The reservoirs R and R' can be moved separately on rods carried by the common platform. In the first instrument made the vessels A and B were turned out of steel because they could be thus made exactly equal on the two sides. This equality is necessary in Oberdeck's method. Making these vessels of steel involved sealing them to glass and this caused more trouble and delay than anything in these experiments. The volumenometer proved a very sensitive method of detecting air leaks. An instrument has now been made all of glass with mercury sealed joints. This has solved the leak trouble.

The manipulation and theory are as follows: With the cups A open to the air the mercury is raised to the marks M and the vessels are then closed. Air is thus imprisoned at atmospheric pressure. The mercury reservoirs are lowered allowing the air volumes V and V' to expand by increments DV and DV' respectively. But during the operation the pressures on the two sides are kept equal by watching the manometer U . Letting p and p' represent the initial and final pressures, we have the relations

$$Vp = (V + DV)p' \quad \text{and} \quad V'p = (V' + DV')p'.$$

The mercury is next raised, restoring the volumes V . A body of volume x is now placed in A . The mercury is again lowered, keeping the pressures equal on the two sides, and giving the air in A , the previous increment DV . This will correspond to an increment DV'' on the right side for equality of pressure p'' . We have then

$$(V - x)p = (Vx - x + DV)p'' \quad \text{and} \quad V'p = (V' + DV'')p''.$$

From the above we have

$$x = \frac{VDV'' - V'DV}{DV''}.$$

If the two volumes are equal, that is, $V = V'$, then

$$x = \frac{V(DV'' - DV')}{DV''}.$$

This is similar to Oberdeck's formula. It is believed that the vertical tubes and the sensitive method of determining equality of pressure on the two sides are an advance.

In working with the above volumenometer, an easier method of manipulation, using a simpler formula suggested itself. Starting as before, we have the relations

$$Vp = (V + DV)p' \quad \text{and} \quad V'p = (V' + DV'')p'.$$

After introducing the body of volume x , we increase the volumes keeping the pressures equal on the two sides, but giving to V' on the right side the previous increment DV'' and getting on the left the new increment DV' . Evidently the pressure is the same p' as above. We thus get

$$(V - x)p = (V + DV' - x)p' \quad \text{and} \quad V'p = (V' + DV'')p'.$$

Substituting for Vp and transposing we get

$$x = \frac{p'}{p - p'} (DV' - DV).$$

The difference of volume increments ($DV' - DV$) is read off in terms of scale divisions of the tube C . The factor $p'/(p - p')$ can be determined directly from the pressures or it can be determined experimentally by placing a body of known volume in A and thus calculating it. This calibration has of course to be done at least once for each series on account of temperature and pressure changes, and the results are then read off direct in scale divisions of the tube. It is to be noted that no assumptions are made here of an equality of volume of the two sides. In getting the volume of turned brass cylinder, which could be accurately calipered, the results were 2.228 c.c. by the volumenometer and 2.210 c.c. by calipering. A steel ball was used for a standard. This shows the accuracy that has been attained ordinarily.

The above experiments were made in the summer and fall of 1906. In *Science Abstracts* for January, 1907, A. Lo Surdo's differential volumenometer is described. This has something of the appearance of the differential form described above, but it is in fact quite different in construction and manipulation.

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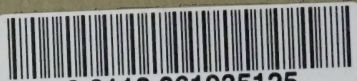
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